RESPONSIVE SIGNAL CONTROL FOR RUSH HOUR TRAFFIC IN AN ARTERIAL

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ABSTRACT

In recent decades, traffic congestion has become a serious problem in major metropolitan areas causing delays, pollution, reduced road safety and degradation of infrastructure. Congestion is mainly concentrated on critical urban arterials that carry high volumes of traffic are mostly managed by traffic lights. To obtain optimality, these traffic control devices should be able to respond to traffic demand and adapt to the likely changes in network conditions. The primary goal of this study is the development of a traffic responsive control strategy to accommodate traffic fluctuations on an urban arterial. Case-based reasoning (CBR), a computational problem-solving paradigm in artificial intelligence (AI), was used to develop a software plug-in, which we have called RESSICA (Responsive Signal Control for Arterial). RESSICA uses an optimal mapping algorithm as an optimization technique with the main control objective of minimizing total vehicular delays, thereby increasing throughput. The developed framework was intensively tested in Quadstone Paramics, a micro-simulation software package, during AM rush hour for Barlow Trail, a major arterial in Calgary, Canada. The performance of RESSICA was compared with existing actuated/pre-timed control strategies. The results show that RESSICA outperformed the existing traffic signal control, in terms of reducing delays, travel times and stops.

Keywords: Case-based reasoning, signal plan, traffic pattern, re-computation, RESSICA.

1 INTRODUCTION

Pre-timed signals represent the most basic type of traffic control system. These systems determine signal variables, such as green splits, cycle lengths and offsets, based on historical data. Although these systems can be adapted through actuated control to respond to recurrent traffic congestion, they are unable to accommodate non-recurrent traffic conditions or random events caused by highly unexpected congestion, due to accidents, weather conditions or special events.

Actuated signal control slightly outperforms its pre-timed control counterpart, since the controller can change signal timing or skip phases, depending on the traffic detected on various approaches. However, the green time in actuated signal is limited by predefined minimum and maximum values, beyond which the system acts like a pre-timed control system. The limitations of pre-timed and actuated signal systems necessitate the implementation of advanced signal systems, such as responsive systems or adaptive traffic control, which are able to accommodate both recurrent and non-recurrent congestion caused by random fluctuations in traffic patterns.

In the last decade, several research efforts related to responsive, as well as adaptive, traffic control have been carried out. These advanced traffic control systems utilize real-time traffic flow data to automatically change the signal timings in response to changing traffic conditions. The system software collects information from vehicle detectors on the actual vehicle flows, occupancies and speeds throughout the arterial network and then obtains the traffic signal timings for each traffic signal based on the prevailing traffic situation.

Different kinds of approaches have been taken in developing these advanced traffic signals, namely: traffic responsive systems that have a look-up table of pre-programmed timing plans, and adaptive traffic systems that optimize the traffic plan parameters online. However, in the literature, these terms are often used interchangeably. While traffic responsive signal control has a library of prepared system timing plans, adaptive signal control system is capable of unlimited signal phasing plan selection. The main focus of this paper is on responsive signal control.

A responsive traffic signal strategy accommodates varying traffic demands and responds automatically to traffic fluctuation. Detectors underneath the road detect traffic patterns and send them to signal controller to choose appropriate timing plans from the signal plan library. This is achieved by continuous on-line mapping of prevailing traffic conditions to the preselected library of signal plans. The signal plan library is prepared off-line in advance for plan selection. Most traffic responsive systems are capable of more than 100 signal plans.

Implementation of responsive signal control requires only a few detectors to be installed, which means that the system may be easily developed without additional infrastructure cost. However, most traffic engineers simply revert to simple time-of-day operation. The reason is largely attributed to the absence of available guidelines on the setup of the traffic responsive mode, which requires a considerable amount of time and resources to design, evaluate and monitor successfully [Abbas et al., 2008]. Additionally, a traffic responsive setup requires the selection of optimal traffic timing plans suitable for a wide range of traffic conditions. Furthermore, these systems need an on-line procedure that maps in real-time the prevailing traffic condition to one of the preselected library of signals. The transition from one signal plan to another should also be as smooth as possible, in order to reduce disruption of traffic flow in the case of changes in the timing plan.

Responsive signal controllers have many advantages. Firstly, since these advanced systems automatically change plans in response to varying traffic demands, these systems reduce the need for frequent redesign/update of the signal timing plans for new traffic patterns, as required for pre-timed operation. Secondly, these systems can result in significant savings in travel time, delays, stops, fuel consumption and reduction of accidents. A study conducted in the Netherlands showed that the implementation of traffic responsive control resulted in a 15% reduction in delays compared to fixed-time operation [Wilson, 1998]. Another study conducted in Texas reported a 13.5% (20.8 million gallons/year) reduction in fuel consumption, a 29.6% (22 million hours/year) reduction in delay, and an 11.5% (729 million stops/year) reduction in stops [Fambro et al., 1996]. This latter study estimated total savings to the public of approximately $252 million in the following year alone. Additionally, Hanbali and Fornal [1997] reported a significant reduction in congestion-related intersection and mid-block accidents after implementing traffic responsive control system in the City of Milwaukee, Wisconsin. The study has also reported an increase in approach capacity and vehicle speed.

This paper consists of six additional sections. Section 2 reviews the literature on responsive signal control. Section 3 briefly introduces the case-based reasoning (CBR) method. Section 4 describes the development of RESSICA step by step. Section 5 sketches the study area and formulates the problem statement. A performance measure of the developed strategy is discussed in section 6. Finally, concluding comments are presented in section 7; and, some future works are outlined in section 8.

2 REVIEW OF THE LITERATURE

The history of responsive control strategy was initiated in the form of first generation control (1-GC) by Urban Traffic Control System (UTCS) of the U.S. Department of Transportation in the early 1970s [Gartner, 1985]. In 1-GC, optimization of signal timing was done off-line but implemented on-line. In second generation control (2-GC), optimization and implementation both were done on-line, but the timing plan could not be implemented shorter than 10 minutes to avoid transition disturbance. The improvement of this strategy led to third generation responsive control (3-GC), where assignment of timing plan was more frequent (3-5 minutes).

This UTCS based responsive traffic control strategy was tested in three cities – Washington, DC, Fort Wayne, IN, and Toronto, Canada – to compare the measure of effectiveness (MOE) of responsive operation with that of time-of-day operation [Kreer, 1976]. This work mainly focused on the effectiveness of the vehicle detector data that was used for implementing the responsive control. It was concluded that, if the quality of traffic data is poor, traffic responsive control strategies are not expected to provide more efficient MOE than the pre-timed control.

The literature also addressed the complication of the computation time needed to match the estimated traffic condition to actual traffic condition and for which a timing plan is assigned. After this time lag, the applied timing plans may not more be suitable for the existing traffic pattern. In other words, by the time control is formulated and deployed, traffic conditions may have changed. These challenges were taken into account during the sensitivity test of UTCS 2-GC . While implementing this strategy in the above three cities, one data set for each city was used and second generation predictor algorithm was tested for both vehicle detector data and historical data for these cities. However, the extensive field test of these strategies prove that the required expectation was not fulfilled.

Jiann-Shiou Yang [2004] developed traffic responsive control to optimize intersection split times after special events at the City of Duluth Entertainment Convention Center (DECC) in Duluth, Minnesota. The developed strategy provided an effective traffic signal timing (over a 30-minute time period) for high volumes of traffic resulting from DECC special events, such as hockey games, concerts, graduation ceremonies, conventions, etc. Using neural network (NN) based simultaneous perturbation stochastic approximation (SPSA), the developed approach adjusted signal timings of six intersections to have coordinated timing plans for this surge of high volume of traffic. Compared to existing green time splits, it was shown that the signal timing plan designed by SPSA was superior (4.65% decrease in total delay per vehicle) to existing timing plans.

Fouladvand et al. [2004] developed traffic responsive signal control algorithms based on the concepts of (a) cut-off queue length and (b) cut-off density. A stochastic model was developed and tested on a single urban intersection having two one-way approaches. *Cellular automata*, a discrete model, was used to sketch the traffic flow. Flow at the approach facing the green light terminated, as long as traffic in the conflicting direction exceeded the cut-off value. The authors found that the developed responsive control provided more efficient timing plans than fixed-time control.

Abbas and his research group developed various responsive traffic signal control logics using genetic algorithms [Abbas & Sharma, 2006]. A multi-objective genetic algorithm (GA) was used to select a minimum number of timing plans in order to optimize the signal timing for a system of four intersections. The system selects a maximum of 16 timing plans for the optimization of the signal timing from a set of 10,353 timing plans obtained from PASSER V. These GA based timing plans are shown to be suitable for a wide range of traffic conditions. Application of these timing plan results in savings of at least 53% in delay and 19% in the number of vehicle stops.

In a recent study, the same authors extended their Traffic Responsive Plan Selection (TRPS) method to successfully optimize the signal timing in response to traffic fluctuation on an arterial in Mexia, Texas [Abbas et al., 2008]. The system selected a set of four timing plans to accommodate all the traffic states in the study area. The research findings showed that the average delay between intersections and for the entire system was decreased after the application of TRPS. Stops and slowdowns on the approach to the intersections were found to improve as well.

Sayers and Bell [2006] developed a traffic responsive signal control strategy using fuzzy logic. The approach was designed to response to traffic demand around an isolated intersection. Inductive loop detectors were placed on the intersection approaches; and, several detectors were embedded in each lane at different distances from the stop line, in order to closely monitor the traffic. The collected traffic data, as well as the data set derived from the detector data, (e.g. degree of occupancy, high occupancy combined with low traffic count, high occupancy combined with high traffic count) were made available for analysis of the traffic flow. The simulation test results of this study indicated an overall delay reduction at junction approaches; and, the response to traffic demand, in terms of assigning appropriate green time, was much quicker.

The most challenging issues in the development of a responsive control strategy are (a) development of appropriate signal timing plan selection for the existing traffic pattern, and (b) transition between signal timing plans. These concerns can be very intricate when the strategy is designed for system-wide traffic. Various directional flows at each intersection constitute a large number of flow variables in the system design, complicating the design further. In addition to the local optimization, in this case, a global optimization takes place for the whole system, in terms of the most suitable timing plan.

In this research, we present a novel methodology for developing responsive signal control strategy for system-wide traffic, named RESSICA (Responsive Signal Control for Arterial), using CBR. The proposed approach alleviates most of the on-line computation burden that was associated with the previously developed approaches. In fact, the CBR technique needs minimum computation and simple matching to find the appropriate timing plans on-line. Using the hypothesis of “a similar traffic pattern should have a similar timing plan”, the approach reduces both computational complexities and steps for optimization. Based on one criteria (green split), the process ranks the traffic patterns (of the signal plan library) by local and global similarity measures and selects an optimal signal plan with a best matched traffic pattern. Although the CBR system goes through a four-step process (retrieve, reuse, revise and retain), its main task is to find a similarity measure. Thus, the CBR method is computationally efficient and requires less time to find the appropriate signal plan compared to the previously developed approaches. Additionally, the proposed approach does not need a neighborhood search for state-plan association, which is required for smooth transition between timing plans. This neighborhood search has been replaced by a simple transition method in the developed strategy.

The developed algorithm checks the traffic patterns of every main approach and cross street to find the similarity with patterns for which signal plans are stored in the system’s library. A best matching pattern is selected from the library, and the signal plan for that pattern is applied to the network. The cycle is repeated every 3 minutes. CBR preserves the experiences of previous problem solving and then adapts them to the prevailing situation. Thus, the system selects a timing plan from the library with minimal re-computation compared to conventional responsive algorithms. As frequent changes in the timing plan create an issue of offset adjustment between two successive timing plans, a transition method called “Add”, which is being used by Eagle, Econolite, NextPhase and Naztec controllers [Shelby et al., 2006], was chosen to coordinate a misaligned phase.

3 CASE-BASED REASONING (CBR)

Case-based reasoning (CBR) is a problem solving-algorithm in the field of artificial intelligence. The very basic idea of the CBR approach is that problems with similar patterns have similar solutions [Burkhard, 2001]. Instead of using generalized relationships for problem solving, CBR is able to use past problem-solving experience. The notion of similarity in this case constructs the background of CBR system: When a new problem arises, the system searches past experience to find the similarity between old cases and the new case. If any similarity is found, the system reuses the previous solution to solve the current problem with minimal re-computation.

CBR has recently been applied to a few transportation problems. The main applications deal with problems requiring heuristic solutions. Whitsitt and Travis [1996] used the CBR method for traffic route generation and adaptation. Since the CBR method uses past experience to solve new problems, the authors found this property can be effective for automated route guidance that needs minimal re-computation, significantly reducing the processing time. Sadek and Morse [2003] applied CBR to assess the benefits of intelligent transportation deployment. The authors compared a dynamic traffic assignment (DTA) model with a CBR based prototype that had been developed for variable message sign based route diversion. The CBR based prototype model yielded a better solution than that obtained from the DTA model.

4 DEVELOPMENT OF RESSICA

In this research, the RESSICA software plug-in was developed based on the application of CBR. The use of CBR for mapping traffic pattern in a system-wide traffic can be explained as follows. The responsive traffic signal system must have a signal plan library, and each signal plan is based on a definite traffic pattern. The CBR system in RESSICA basically deals with the traffic pattern of the corresponding signal plan from the signal plan library to provide an optimized solution for system-wide traffic. The traffic pattern mapping process can be split into a four-step process, as depicted in Figure 1:

1. RETREIVE traffic patterns from the traffic pattern library (which corresponds to the signal plan library) that are similar to the existing traffic patterns.

2. REUSE the adapted solution(s) of the successful case(s) to the prevailing traffic pattern.

3. REVISE the proposed solutions, if necessary, for reuse according to the evaluation of the new experience.

4. RETAIN the updated experience (as a new case) to be used for future applications.

The RETRIEVE step is important for the speed of the CBR process, as the similarity measure plays an important factor in this step. The quality of the retrieved traffic pattern is solely determined by similarity; and, a closer traffic pattern yields less effort to reuse and a better chance of successful case. The RETAIN step process updates the system for the next use by including this experience of problem solving. This four-step process forms a CBR cycle. The update is performed at a certain time step interval, which, in our case, is 3 minutes. Traffic pattern is collected for this duration and signal plan is updated for the detected pattern at the end of each interval.

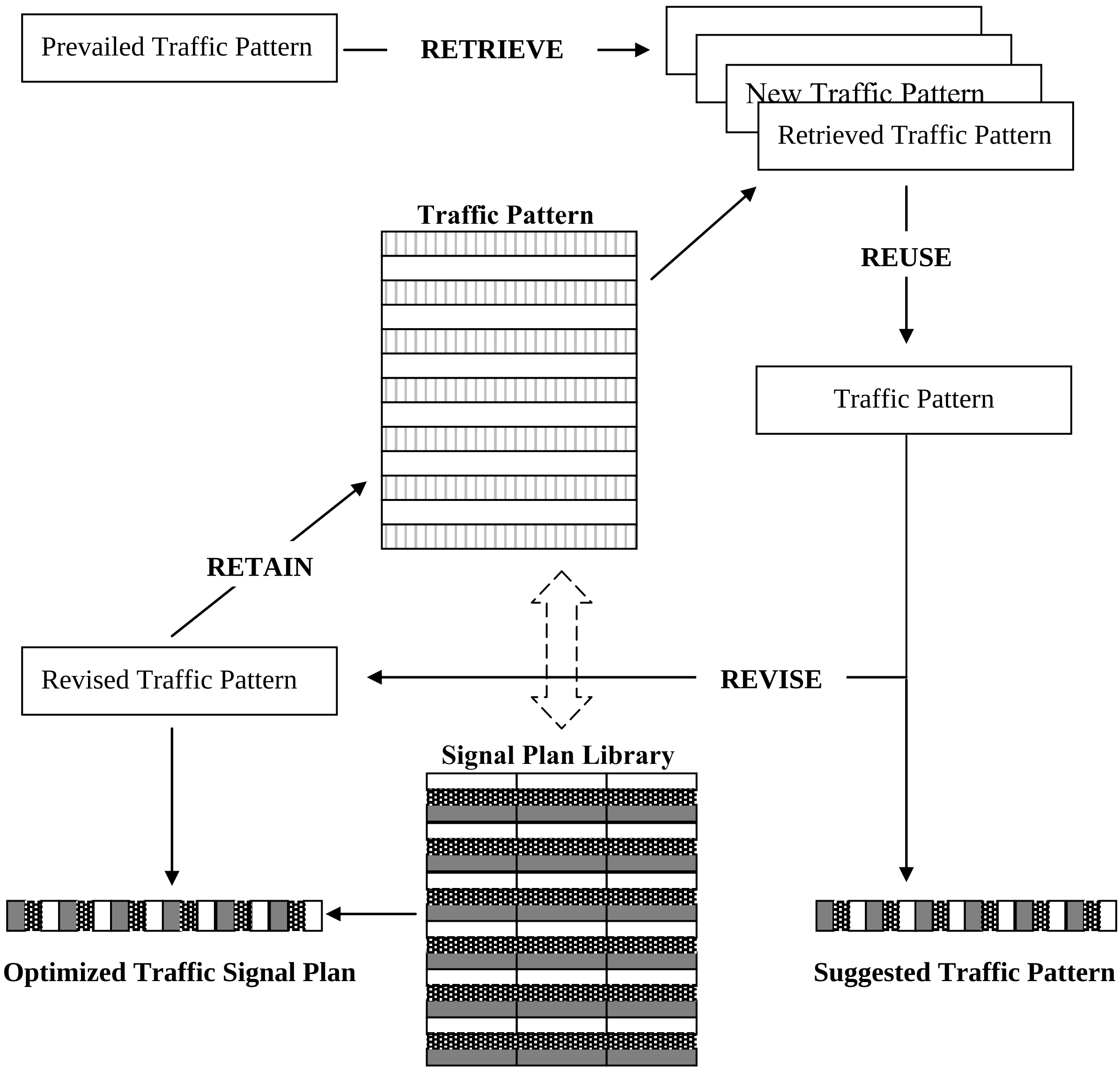


Figure 1 – Cased-based reasoning approach in RESSICA

Figure 1 demonstrates the specific cycle of sequential steps for the CBR method used in RESSICA. The case base at the core of the CBR process is the traffic pattern library, which stores previous instances of problems (i.e. traffic patterns). When a new traffic pattern in the corridor network is detected by the system, the CBR method matches the new traffic pattern with the traffic pattern stored in the case base. Based on the similarity measure, which is explained in details in section 4.2, a traffic pattern is retrieved from the case base. The retrieved traffic pattern is then tested for similarity and given a rank based on the similarity measure. It is expected that there may be some dissimilarity between the retrieved traffic pattern and the existing (detected) traffic pattern. If the suggested traffic pattern is not the most similar one (rank is not highest), a revision process takes place by retrieving another traffic pattern from the library, which is checked for similarity. This recursive process finds the most similar traffic pattern (with highest ranking) from the traffic pattern library, and the corresponding signal plan is selected automatically from the signal plan library for the existing traffic pattern. This new experience can be retained in the system for future use with minimal re-computation. Thus, the system requires less computation effort and time, which essentially reduces the time lag between the initialization of the CBR cycle and application of an updated timing plan.

4.1 Development of Signal Plan Library

In this paper, the traffic responsive signal was developed for a specific arterial in the City of Calgary, Canada. Different possible traffic patterns were considered while developing the signal timing plan library. Both historical data and simulated data from Paramics micro-simulation were gathered to cover most of the likely traffic patterns. The prevailing traffic patterns are detected from Paramics by installing inductive loop detectors on all the approaches of the intersections in the examined arterial. The data included 24 historical traffic counts and 40 simulated traffic patterns covering AM, PM and off-peak traffic variations. With the resulting simulated and historical turning movement counts, the intersections in the study area were optimized and coordinated in Synchro, a traffic signal design software package [Trafficware, 1993-2005]. As a result, 64 timing plans with different offsets were developed and stored in the CBR signal plan library.

4.2 CBR Mapping Algorithm

The mapping algorithm establishes similarity between retrieved traffic patterns and prevailing traffic patterns. The traffic pattern, T_p, is identified by the link flows *(*τ) on all intersection approaches of the four signals simultaneously. These prevailing link flows have to be matched with the link flows (ρ) of the traffic pattern, E_p, stored in the traffic pattern library. From these similarities, the system selects a timing plan that corresponds to the matched link flow. The algorithm can be organized as such:

$$(T_p)_e = \{\tau_1, \tau_2, \tau_3, ..., \tau_n\} \quad ......(1)$$

$$(E_p)_l = \{\rho_1, \rho_2, \rho_3, ..., \rho_n\} \quad ......(2)$$

where, subscripts e and l denote traffic pattern in “existing” and in “library” respectively.

The similarity measure, S, between E_p (traffic pattern from the library) and T_p (the detected traffic pattern from Paramics) is quantified based on the degree of similarity. The range of S is considered in the interval of (0, 1) where 0 denotes most dissimilar traffic pattern(s) and 1 represents the most similar traffic pattern(s). Two similarities are developed: local similarity and global similarity. If the network consists of m intersections, the CBR method computes a local similarity measure, sim_j, for each intersection (where $j=1\sim m$) by mapping the existing traffic pattern, T_p with the traffic pattern stored in the library, E_p.

$$sim_j : (T_p)_e \times (E_p)_l \rightarrow S \qquad \text{.....(3)}$$

The similarity score, S, is computed from local similarity measures that find similarity between existing link flow, τ_i, and link flow in traffic pattern library, ρ_i, based on green time. The green time for each link is directly related to the link flow as described in equation (4). The relationship is chosen to develop similarity measures between a query and a case. The query, in this case, denotes green time required for a link flow of the detected traffic pattern; whereas, the case denotes green time assigned for the link flow (for same link as query) in the traffic pattern library.

$$\left.\begin{array}{l} g_\tau = \varphi \times \tau_i + \varepsilon \\ g_\rho = \varphi \times \rho_i + \varepsilon \end{array}\right\} \qquad \text{.....(4)}$$

where, g_τ = green time required for link flow, τ_i, in the detected traffic pattern,
g_ρ = green time assigned for link flow, ρ_i, in the Traffic Pattern Library,
τ_i = link flow at i^{th} link in the detected traffic pattern (query),
ρ_i = link flow at i^{th} link in the Traffic Pattern Library (case),
φ,ε = constants.

Local similarity measures were considered in the range of (0, 1), where 0 denotes minimal similarity and 1 implies maximal similarity between g_τ and g_ρ in the same sense as between τ_i and ρ_i. The similarity measure in RESSICA relies on the difference between traffic patterns, which is obtained from the difference in link flows, τ_i-ρ_i. Equation (5) describes the local similarity at each of the four intersections:

$$sim_j([\tau_1, \tau_2, \tau_3, ..., \tau_n], [\rho_1, \rho_2, \rho_3, ..., \rho_n]) = \frac{1}{n} \cdot \sum_{i=1}^{n} \frac{1}{1 + |\tau_i - \rho_i|} \qquad \text{.....(5)}$$

where n = the number of links at each intersection.

It should be noted that the parameterized weight value in this CBR system is assumed to be equal to 1.0, meaning that the system does not consider any priority to a particular link flow. All the link flows for the four intersections are treated equally, and the mapping of the traffic pattern determines how much green time should be given to a particular link. The similarity measure for the whole network is found by global similarity, which is obtained by:

$$SIM([\tau_1, ..., \tau_n], [\rho_1, ..., \rho_n]) = COMP(sim_1(\tau, \rho), ..., sim_m(\tau, \rho)) \qquad \text{.....(6)}$$

In equation (6), the global similarity, SIM, combines (with the composition function, $COMP$) all the local similarities, sim_j, in order to get the most similar traffic patterns for the system-wide traffic. For each of the traffic patterns in the library, the system determines a maximum possible similarity score for global similarity. The highest global similarity score denotes most the similar traffic pattern, E_p for existing pattern, T_p.

Maximum similarity means the maximum preference for choosing that particular link flow (local level), i.e. there is a strong reflexivity between these two link flows. On the other hand, minimum similarity is not as exact as maximum similarity. It may not have impact on global similarity [Burkhard, 2001].

4.3 Transition of Signal Plans

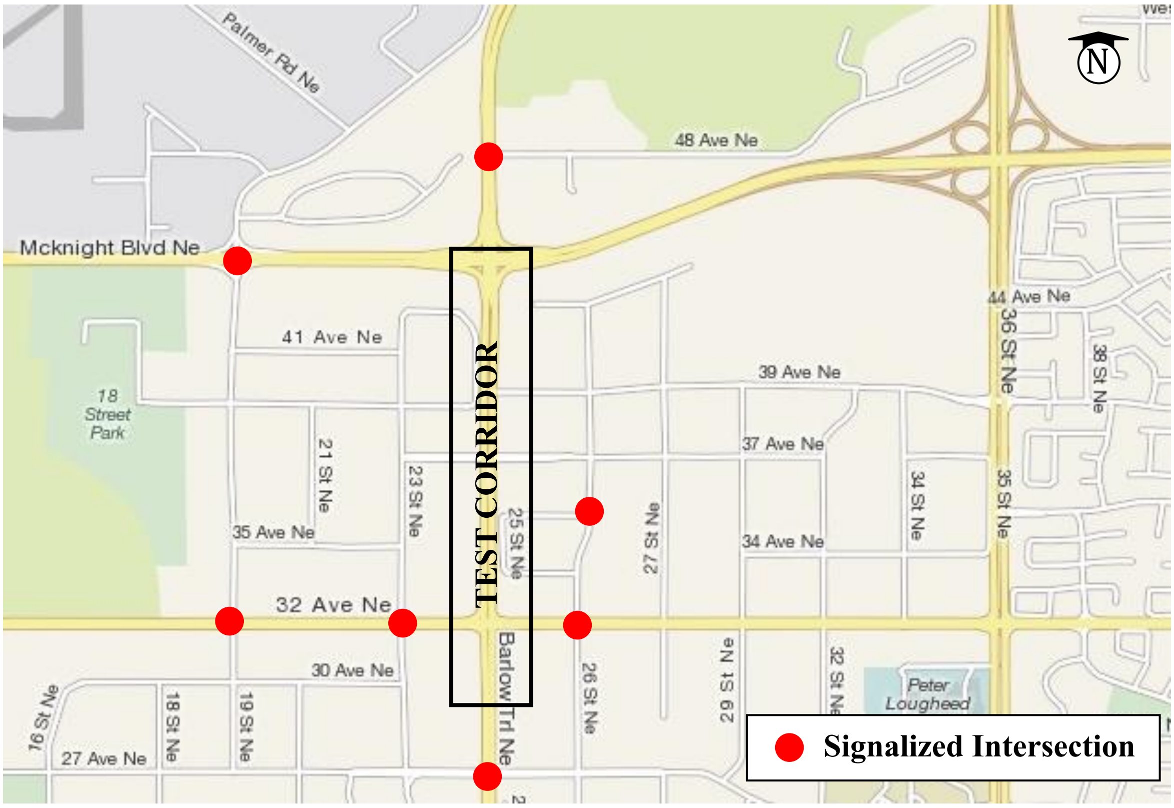
Transition plays an important role in the selection of traffic responsive signal plans [Shelby et al., 2006]. It reduces the disruption of traffic flow during changes in timing plans. During a given time period in the signal timing, phase timings are updated in order to achieve coordination between old and new timing plans in a smoother way. Shelby et al. [2006] reported several methods of transition that can be used for various controllers. In this research, we choose the “Add” method developed by Shelby et al. [2006] to be implemented in conjunction with the developed responsive control strategy. The Add method had better results in CORSIM simulation [Shelby et al., 2006].

When the switching of signal plans occurs, the offset is corrected by lengthening the cycle time. Each of the phases in a cycle gets some extra green time to accommodate this increment in cycle time. The usual increment of cycle time in the Add method is constrained to 20%. The longer cycle time continues in the subsequent cycles until the offset has been adjusted for coordination. Let’s assume that the current signal timing plan has zero offset and the new signal plan has an offset ψ and a cycle length of C seconds with four phases *(Ø$_1$, Ø$_2$, Ø$_3$, and Ø4)*. The method of transition corrects the offset, typically by increasing the duration of all phases of the new timing plan.

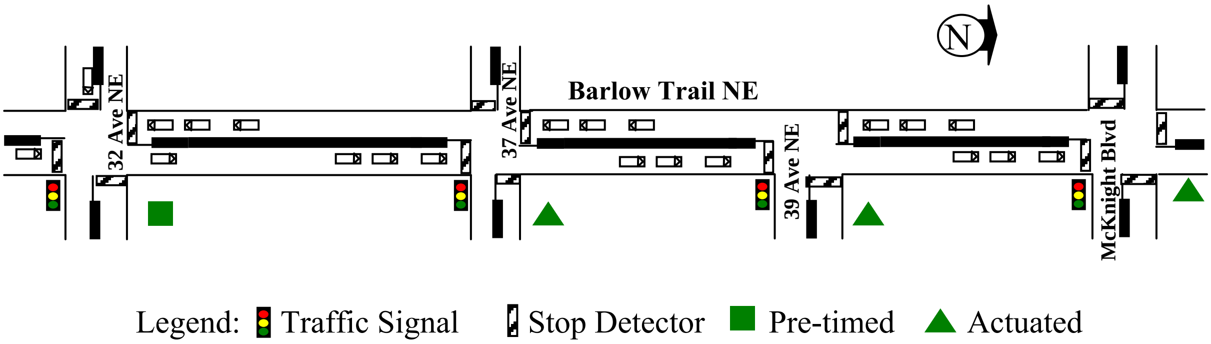
$$\phi_1^{'} = \phi_1 + \Delta_1 , \phi_2^{'} = \phi_2 + \Delta_2 , \phi_3^{'} = \phi_3 + \Delta_3 , \phi_4^{'} = \phi_4 + \Delta_4 \ldots\ldots\ldots\text{(7)}$$

$$\Delta_1 + \Delta_2 + \Delta_3 + \Delta_4 = \psi / n = 0.2 \times C \quad \ldots\ldots\ldots\ldots\text{(8)}$$

where n implies the number of subsequent cycles required for offset adjustment, $\Delta_1, \Delta_2, \Delta_3, \Delta_4$ are additional green times added to the corresponding phases, and ψ/n should not exceed some specified percentage of C (20% in this case). The additional green time, Δ, must be proportional with green splits of that cycle.



(a)



(b)

Figure 2 – Case Study: (a) Barlow Trail NE, Calgary, Canada and (b) Test Corridor on Barlow Trail NE

5 CASE STUDY

The objective of this research is the development of responsive signal control for an arterial. As shown in Figure 2(a), part of Barlow Trail NE, in the City of Calgary, Canada, was chosen as a case study. The selected study area was simulated in Paramics to test the developed control strategy. The study area experiences high traffic demand during rush hours (from 6:00 to 9:00 a.m. and 3:00 to 6:00 p.m.). In addition, the test corridor intersects with two major roads – McKnight Boulevard and 32 Avenue NE – which input a high volume of traffic during rush hours. Among the four intersections, three of them are operated by an actuated controller and one with pre-timed, as depicted in Figure 2(b). Hence, the research aimed to test the following properties of RESSICA:

1. Matching of the most similar traffic pattern for the 21 link flows [6 (32Ave) + 4 (37 Ave) +3 (39 Ave) +8 (McKnight Blvd)] using CBR.
2. Application of a signal timing plan for the most similar traffic pattern at the desired time interval.
3. Smooth transition while switching the signal timing plans.

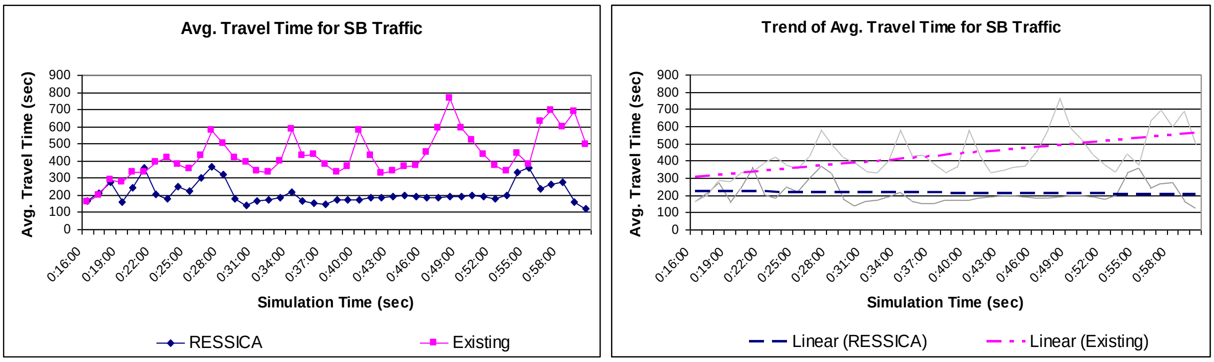
The study area was coded in Paramics. The simulated model was loaded with an origin-destination (O-D) matrix representing AM peak period for a length of one hour. The O-D demand was obtained from the City of Calgary, based on a 2001 household survey. This O-D matrix was then calibrated in Paramics Estimator based on recent traffic counts. For simplicity, non-recurrent traffic congestion during AM peak period was not considered. The simulated model was calibrated based on different parameters, such as screen line count, intersection blockage, signal phase overlapping, O-D routing, turn counts, etc.

6 RESULTS OF EXPERIMENTS

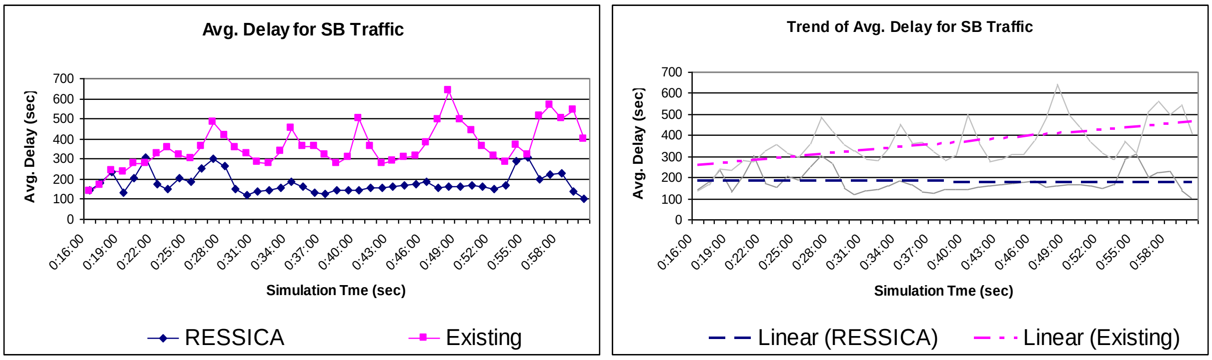
This section presents an evaluation of the performance of RESSICA and an examination of its sensitivity to traffic fluctuation during AM peak period in a micro-simulation environment. The existing signals plans in the test corridor were updated recently by the City. The focus was the comparison of the performance of the responsive control with the existing actuated/pre-timed signal control in the study area. For this purpose, the study area was simulated in Paramics for one hour of rush hour traffic during AM peak. A 15-minute warm-up period was provided to obtain reliable estimates of traffic, and the data for travel time study were collected for the remaining 45 minutes. During AM peak period, traffic is attracted to the central business district, which is located south of the study area. Thus, the analysis of the results considered southbound traffic for travel time comparisons and all four intersections for comparing intersection delays.

The simulated results were collected from three different simulation runs (for three different seed numbers). The seed number is responsible for random traffic generation throughout the network. For each seed number, the average travel time, delay and stops for critical movements were determined via the Paramics Analyzer; and, the performance of RESSICA was compared with the existing traffic controls. The average results of the three seeds were reported and are discussed below. At the end of each specified period, the overall intersection delays were evaluated for the study network to better understand the performance of RESSICA in improving delays in the approaches rather than only the southbound approach.

As shown in Figure 3(a), in general, the average travel time for vehicles travelling southbound on Barlow Trail from McKnight Blvd to 32 Ave NE was reduced significantly



(a)



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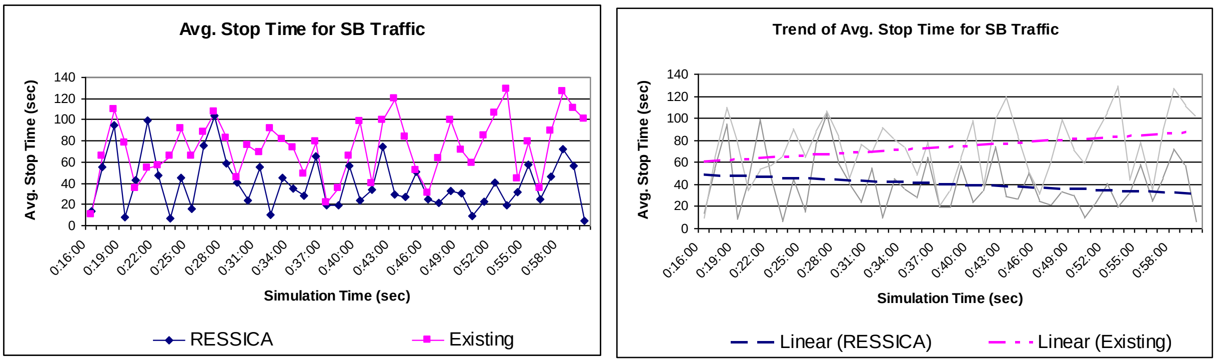

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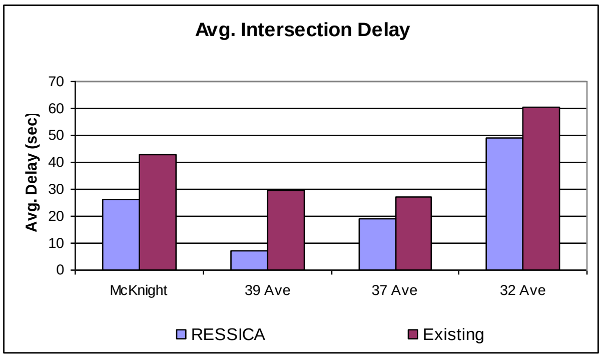

(d)

Note:

1. Traffic simulation was performed for one hour with three different seed numbers.
2. Warm-up period is 15-min.
3. Results were reported from the average of three different simulation runs.

Figure 3 – Performance Measures of RESSICA during AM peak period on Barlow Trail, Calgary

throughout the simulation runs with the application of RESSICA, compared to that of the existing signal controls. Every 3 minutes, RESSICA gathered information on traffic at the various approaches and adjusted the green time by changing the timing plan to accommodate the prevailing traffic condition. This resulted in smoother traffic overall and, consequently, lower travel time. In contrast, the existing actuated traffic controllers at the four intersections were incapable of accommodating the existing demand by assigning the extra green time needed to accommodate southbound traffic.

Figure 3(a) shows that at the beginning of the simulation runs, the performance of RESSICA and the existing controller were somehow similar, followed by a little oscillation of the performance of RESSICA. This fluctuation in the performance of RESSICA may be due to the experimentation and learning stage of the CBR method. After a while, the system seemed to stabilize, as the suitable signal plan was selected, resulting in reduced travel time. However, at the end of the 1-hour simulation run, RESSICA again showed some fluctuations in its performance. This may be explained by a possible queue blocking the intersection of 32 Ave NE, due to a downstream signal that is outside the study area. However, overall, the travel time for the southbound traffic improved with RESSICA, compared to the existing controllers, as indicated in the trend lines (Figure 3(a), right-hand-side).

In fact, the trend lines shows that the performance of the existing signal controls deteriorated further with time (i.e. increased travel times over the simulation run), while RESSICA was able to stabilize the travel time in this closed network. The failure of the actuated signal control to accommodate the traffic was mainly due to the presence of an upper threshold in its control logic, which resulted in residual queues that could not be fully dissipated and accumulated further from one cycle to another and probably resulted in a gridlock.

As shown in Figure 3(b), southbound traffic travelling from McKnight to 32 Ave NE also faced considerably reduced delays with the application of RESSICA. With the actuated/pre-timed signal controllers, each intersection operated independently, which resulted in longer delays for the traffic. On the contrary, RESSICA responded to traffic travelling the route, more specifically for the network as a whole, by coordinating the 4 traffic signals. Therefore, the waiting time at each intersection was greatly reduced.

Figure 3(c) compares the delays due to stops for the examined signal control logic. The figure demonstrates that RESSICA significantly reduced the disruption of traffic flow and caused limited stops at the intersection approaches. The experience based expert system embedded in the developed approach was able to timely update the traffic signal plan in response to traffic fluctuation. This resulted in minimal stops over the simulation runs as can be observed from trend line (Figure 3(c), right-hand-side).

Figure 3(d) showed that, for the four intersections, RESSICA also outperformed existing signal controllers in terms of intersection delay. Among the four intersections, traffic at the 32 Ave / Barlow intersection faced the maximum delay for both traffic control cases. For the existing condition, the intersection was operated as pre-timed; therefore, traffic surges from upstream intersections could not dissipate within the allocated green time. When RESSICA operated at this intersection, traffic was delayed due to an uncoordinated signal at the downstream intersection (outside the study area). Still, RESSICA was able to result in shorter delays compared to the existing pre-timed control.

Table 1 summarizes the results of the simulation runs for southbound traffic during AM peak period. With the implementation of RESSICA, travel time, delays and stops dropped by around half compared to the existing signal condition. These results show the superiority of RESSICA over conventional actuated/pre-timed signal control in response to traffic fluctuation during rush hours.

Table 1 – Travel Time Study for Southbound Traffic within the Study Network

	Avg. Travel Time	**Avg. Delay**	**Avg. Stop Time**
RESSICA	213 sec	181 sec	40 sec
Std. Deviation	60	50	24
Existing Control	433 sec	361 sec	74 sec
Std. Deviation	127	103	28
Improvement by RESSICA	-51%	-50%	-46%

7 CONCLUSION

Few research works have deployed traffic responsive signal control for system-wide traffic. The objective of this paper was the development of a traffic responsive signal control strategy for an arterial that experiences large fluctuations in traffic demand. With this aim, case-based reasoning, a computationally efficient artificial intelligence technique, was used to develop a responsive signal control that we have called RESSICA (Responsive Signal Control for Arterial).

The performance of the developed framework was tested in Paramics for AM rush hour on a simulated network consisting of four intersections. The results of the micro-simulation runs showed that RESSICA outperformed the existing signal traffic control, in terms of reducing travel time, delay and stop time, and by minimizing intersection delay for each of the intersections within the closed network. The analysis results also proved that RESSICA is capable of handling system-wide traffic during rush hours by coordinating the traffic at the various intersections. The residual queues and occurrence of gridlocks that resulted with the existing control during the high AM traffic demand were reduced or eliminated.

In conclusion, the development and performance measures of RESSICA proved that most suitable traffic plans can be applied to a system-wide traffic with minimal re-computation and effort, leading to reduced travel time, delay and stops over the route.

8 FUTURE WORK

This paper focussed on recurrent congestion. The next step of this research is the extension of the capability of RESSICA to respond to non-recurrent congestion resulting from random incidents, such as accidents, construction, scheduled maintenance, etc. Weather responsive timing plans may also be included in RESSICA, in order to make the system responsive to road weather conditions, in addition to traffic congestion. A traffic prediction algorithm may also be developed to reduce the time lag between the time the signals are implemented and the prevailing traffic conditions. Future research should consider testing RESSICA in the field.

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REFERENCE

Abbas, M. M., Pesti, G., Chaudhary, N. A. and Li, P. (2008). Configuration Procedure of Traffic-responsive Plan Selection of an Arterial Network. In: CD_ROM, Transportation Research Board of the National Academies, Washington, D.C., January 2008.

Abbas M. and A. Sharma. (2006) Multi-Objective Plan Selection Optimization for Traffic Responsive Control. In: ASCE Journal of Transportation Engineering, Vol. 132, No. 5, 2006, pp. 376-384.

Burkhard, H. (2001). Similarity and Distances in Case Based Reasoning. In: Fundamenta Informaticae, Vol. 47, pp. 201-215.

Fambro, D., S. Sangineni, C. Lopez, S. Sunkari, and R. Barnes. Benefits of the Texas Traffic Light Synchronization (TLS) Grant Program II. Texas Transportation Institute, The Texas A&M University System, College Station, Texas, 1995.

Fouladvand, M.E., Sadjadi, Z. and Shaebani, M.R. (2004). Optimized Traffic Flow at a Single Intersection: Traffic Responsive Signalization. In: Journal of Physics A: Mathematical and General, Vol. 37, pp. 561-576.

Gartner, N. H. (1985). Demand-Responsive Traffic Signal Control Research. In: Transportation Research, Vol. 19A, Issue 5/6, pp. 369-373.

Goldstein, N.B. and Kumar, K.S.P. (1982). A Decentralized Control Strategy for Freeway Regulation. In: Transportation Research, Vol. 16B, No. 4, pp. 279-290.

Hanbali, R. and C. Fornal (1997). Methodology of Evaluating the Effectiveness of Traffic-Responsive System on Intersection Congestion and Traffic Safety. In: Transportation Research Record 1603, TRB, National Research Council, Washington, D.C., pp.137-149.

Isaksen, L. and Payne, H.J. (1973). Suboptimal Control of Linear Systems by Augmentation with Application to Freeway Traffic Regulation. In: IEEE Transactions on Automatic Control, Vol. 8, No. 3, pp 210-219.

Kreer, J.B. (1976). Factors Affecting the Relative Performance of Traffic Responsive and Time-Of-Day Traffic Signal Control. In: Transportation Research, Vol. 10, pp. 75-81.

Sadek, A. and Morse, S. (2003). Case-based Reasoning for Assessing Intelligent Transportation Systems Benefits. In: Computer-Aided Civil and Infrastructure Engineering, Vol. 18, pp. 173-183.

Sayers, T. and Bell, M. G. H. (1996). Traffic Responsive Signal Control Using Fuzzy Logic—A Practical Modular Approach. In: Proceedings of the Fourth European Congress on Intelligent Techniques and Soft Computing, Aachen, Germany, pp. 2159-2163.

Shelby, S. G., Bullock, D. M. and Gettman, D. (2006). Transition Methods in Traffic Signal Control. In: Transportation Research Record, 1978, pp. 130-140.

Trafficware (1993-2005). Help file. Sycnchro version 6, Trafficware Limited.

Whitsitt, A. J. and Travis, L. E. (1996). Traffic Route Generation and Adaptation Using Case-Based Reasoning. In: Journal of Intelligent Transportation Systems, Vol. 3, No. 3, pp. 181-204.

Wilson, A. (1998). A Traffic-Responsive Control Method for Small Networks. In: Towards the New Horizon Together. (NHTV, Breda, Netherlands). Proceedings of the 5th World Congress on Intelligent Transportation Systems, Held 12-16 October 1998, Seoul, Korea. Paper No. 2020.

Yang, J.-S. (2004). Special Events Traffic Signal Timing Control via a SPSA Optimization Algorithm—A Case Study. CD-ROM: Transportation Research Board of the National Academies, Washington, D.C., 2004.